APPROVED FOR FALL 2017 ONLY

Lab 0 —Line Sensing QRE1113 Reflectance Sensor

Table of Contents

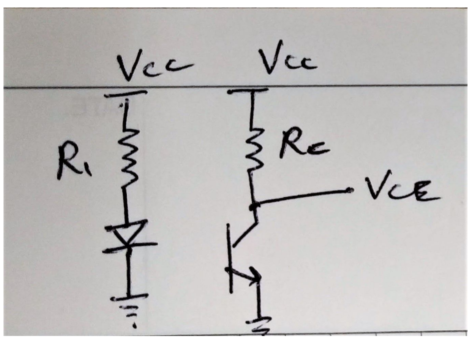
Overview

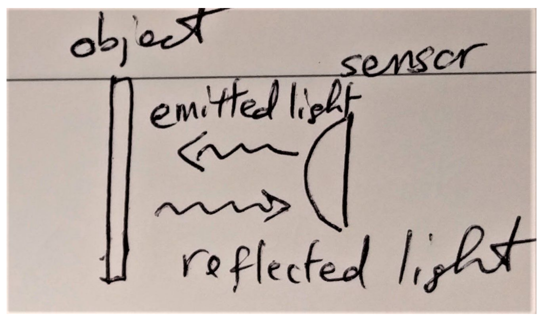
By Miki

IR sensors are commonly used in robotics to detect obstacles and for line following applications. We are using IR sensors for our robots to detect the lines along the 2D maze surface. If our robots can detect a range of grayscale values, so they can navigate the maze. With our current parameters, the IR sensors cannot detect a large range of grayscale values (i.e. low resolution detection).

Goal: Design a circuit that maximizes the resolution of the IR sensors for our robots to navigate through the maze.

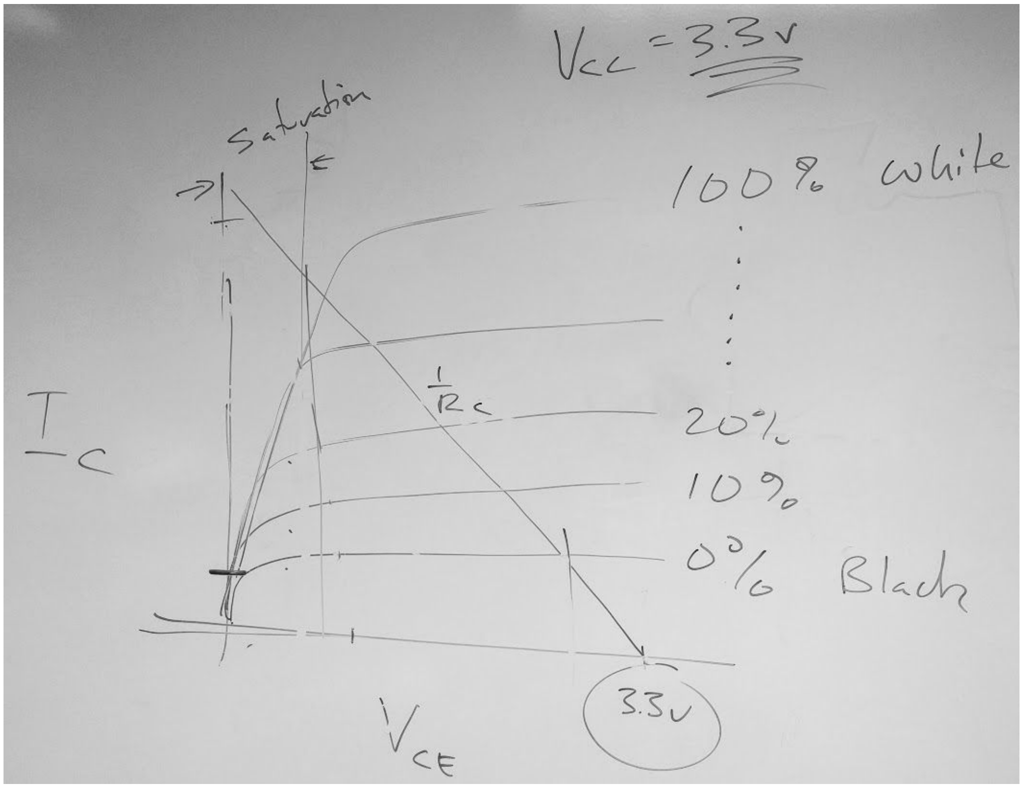
The QRE1113 sensor consists of an IR emitting photo diode and an IR sensitive phototransistor. The photodiode emits IR light that gets reflected back to the sensor when an object is in the light's path.





The phototransistor inside the sensor detects the reflected IR light. The base of the phototransistor is open (not connected – floating). When the reflected IR light enters the base of the phototransistor, the light is converted into a base current that controls the collector current of the transistor (EE330 comes in handy here).

The intensity of reflected IR light determines the curve for the current flowing into the collector, as shown in the following graph (Ic vs. Vce). When the intensity of reflected IR light into the base increases, the collector current will increase (i.e. move to a higher curve).



We then place a load line across the graph. The load line represents Vce, the voltage across the transistor (from collector to emitter). This is the voltage that is read by the ADC in the microcontroller. We can derive the load line using simple KCL:

$$3.3V = I_c R_c + V_{ce}$$

Solve for Ic to get the equation of the load line:

$$I_c = \frac{3.3}{R_c} - \frac{V_{ce}}{R_c}$$

In order to maximize resolution, we need to choose the best load line. We therefore need to design a circuit that uses the best value for Rc.

Here is link to the [QRE1113 Miniature Reflective Object Sensor]() used in the SparkFun [Analog]() (Figure 1) and [Digital]() Line Sensor Breakout boards. Here is a short tutorial on the [Line Sensing QRE1113 Reflectance Sensor + Arduino](), which explains the difference between the Analog and Digital [signal conditioning]() circuits used with the QRE1113. In this lab we will breadboard the "discrete" version of the SparkFun breakout board as shown in Figure 2.

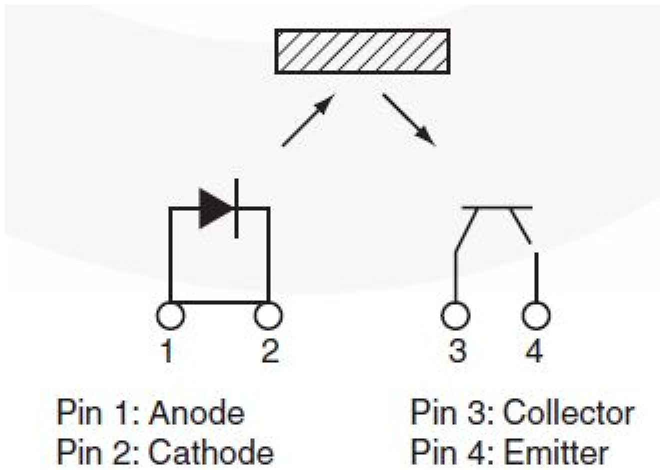


Figure 1 [QRE1113 Miniature Reflective Object Sensor]

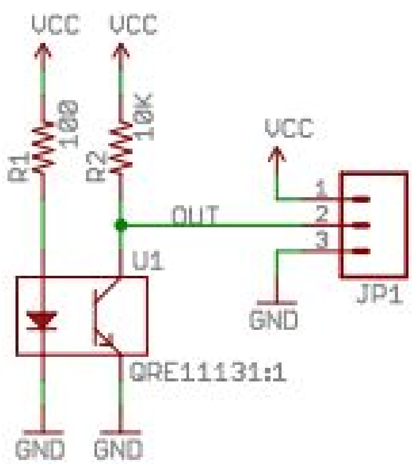


Figure 2 [Schematic] **of SparkFun Analog Line Sensor**

Experimentally it has been shown that resistors R1 and R2 used in the Sparkfun "Analog Line Sensor" circuit (Figure 2) do provide a linear output across a uniform grayscale. One of the objectives of this lab is to experimentally determine the optimal resistor values for R1 and R2. To accomplish our objective we will conduct a series of experiments.

From Figure 3 below we see that there are four (4) independent variables

1. **Grayscale target**
2. **Distance to target (variable d)**
3. **LED current (variable I_F)**
4. **Phototransistor bias (DC load line, slope = $1/R_2$)**

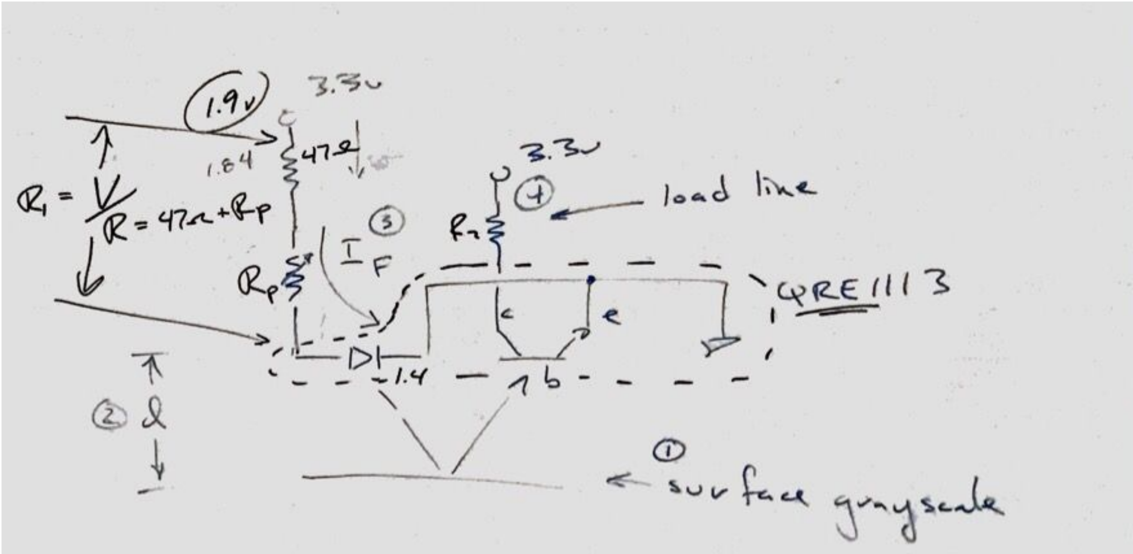


Figure 3 Experimental Circuit

Lab Supplies

- **QRE1113 Miniature Reflective Object Sensor (provided)**
- **47 ohm resistor and Set of Resistors**
- **Multi-turn variable resistor - anything above 100 ohms and less than 1K ohm**
- **Mini , half, or normal breadboard with Jumpers**
- **Multimeter**
- **Cables with alligator clips for ECS-314 lab equipment**
- **Large Post-it Notes or Yellow Pad (may be provided)**
- **Large Binder Clip(s)**
- **Hole punch and/or X-Acto knife, a steel ruler, and a cardboard surface to cut on. (See Note 1)**
- **Micrometer (optional)**
- **Sparkfun ATmega32U4 Pro Micro - 3.3V/8MHz , Arduino Leonardo , or Arduino UNO.**

Note 1: One group will be running the labs in ambient light. This group not need the a hole punch or X-Acto knife.

Arduino Code

```
//Code for the QRE1113 Analog board
//Outputs via the serial terminal - Lower numbers mean more reflected

int QRE1113_Pin = 0; //connected to analog 0

void setup() {
  Serial.begin(9600);
  See Note 2
}
```

```
void loop() {
  int QRE_Value = analogRead(QRE1113_Pin);
  Serial.println(QRE_Value);
}
```

Source: Line Sensing QRE1113 Reflectance Sensor + Arduino

Note 2: As shown in Figure 3 "Experimental Circuit" the circuit is powered from a 3.3v source (Vcc = 3.3v). If you are using a 3.3v Arduino (3DoT or ProMicro 3.3v/8MHz) then no action is required. If you are using a 5v Arduino then power the circuit from the 3.3v output pin and wire a jumper from 3.3v to the AREF input pin. In addition before taking any measurements be sure to set the reference voltage to AREF. Consequently, all analog measurements with be taken with the reference voltage set to 3.3v.

```
analogReference(EXTERNAL);
```

Arduino Output using Serial Monitor (Print) and Serial Plotter

Excellent Video tutorials on Arduino Print function (Part 1 and Part 2), analogRead (Part 1 and Part 2). Here is documentation on using the Arduino Serial Plotter (Arduino IDE versions 1.6.7 and later).

- **Arduino Forum**
- **Instructables**

Bonus Points: You may want to also export your data and plot in Excel or Matlab.

Experiment 1 - Optimum Distance to Target

1. **Grayscale target - White Paper**
2. **Distance to target - independent variable [0.2mm steps, 0 - 5mm]**
3. **LED current = 20 mA**
4. **Phototransistor bias (DC load line) = 10K**

Experimental Setup

As discussed in lab. You will need the following.

- **Notebook paper**
- **Voltmeter and variable resistor - record voltmeter accuracy**
- **Arduino microcontroller board (3DoT, Sparkfun ProMicro 3.3v, Leonardo, Uno)**

Important Notes:

1. **As shown in Figure 3 the circuit is powered from a 3.3v source (Vcc = 3.3v). If you are using a 3.3v Arduino (3DoT or ProMicro 3.3v/8MHz) then no action is required. If you are using a 5v Arduino then power the circuit from the 3.3v output pin and wire a jumper from 3.3v to the AREF input pin.**
2. **All experiments should not allow room lighting to reach phototransistor.**

Experimental Output

For each experimental step d = 0 - 5mm, in ≃ 0.2mm steps take readings using a voltmeter and as read from the Arduino serial output port (`analogRead`).

Solving the equation provided in the [Analog-to-Digital lecture](#) and provided here for V_{IN}, convert the Arduino ADC output (units are a Digital Number - DN) into its corresponding voltage (V_{IN}).

$$ADC = \frac{V_{IN} \cdot 1024}{V_{REF}}$$, where V_{REF} = 3.3v

Using Ohm's law, and measured value for R2 (≃ 10KΩ), calculate Ic. On one graph using two different notations (ex. X = Voltmeter, O = Arduino) plot your experimental results. Using Excel, Matlab, etc. curve fit your experimental results for both sets of readings (again on a single plot). Your resulting plot should take the form shown in Figure 4. Differences from this figure include IF = 20mA, VCE = 3.3v, TA = measured; Two plots (Voltmeter, Arduino) and no "Mirror" plot; Actual current (not Normalized).

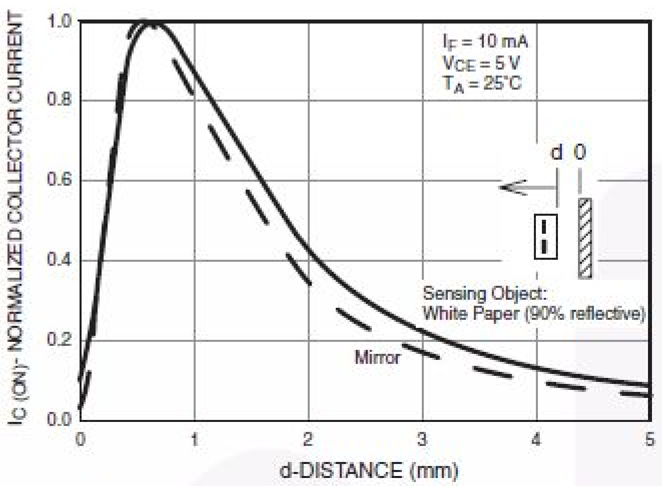


Fig. 1 Normalized Collector Current vs. Distance between device and reflector

Figure 4 Collector Current vs. Distance between device and target

Based on team assignment set d = [Optimum, 1, 2, 2.5, 3, 3.5, 4] mm

Experiment 2 - Optimum LED Current and R1

1. [Grayscale target](#) - White Paper
2. Distance to target d - ***Based on team assignment***
3. LED current = independent variable I_F = 0 - 40 mA, in 2 mA steps
4. Phototransistor bias (DC load line) = 10K

As in most engineering problems there is a tradeoff to be made. In this case we want to use the minimum amount of power, while also achieving the best resolution possible.

Experimental Output

For each experimental step I_F = 0 - 40 mA, in 2 mA steps take readings using a voltmeter and as read from the Arduino serial output port (`analogRead`). Following the procedures outlined in Experiment 1, create a plot, which should take the form shown in Figure 5. Differences from this figure include Two plots (Voltmeter, Arduino).

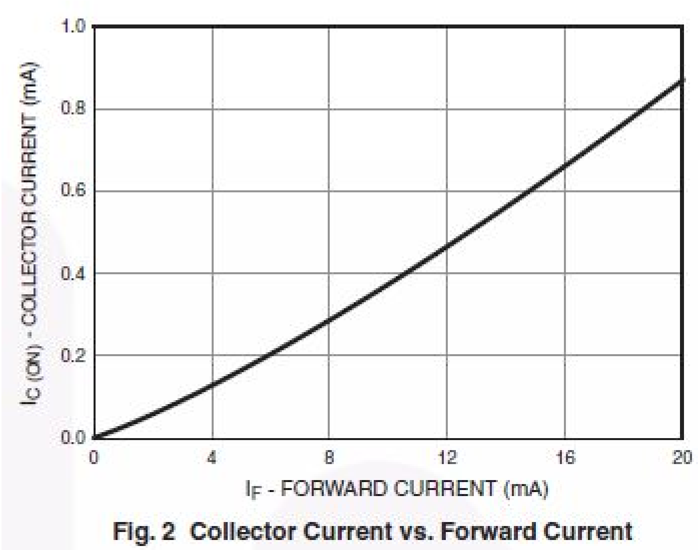


Figure 5 Collector Current vs. Forward Current

As an ancillary objective measure the forward voltage (V_F) drop at different forward current values (I_F). For each experiment record the room temperature.

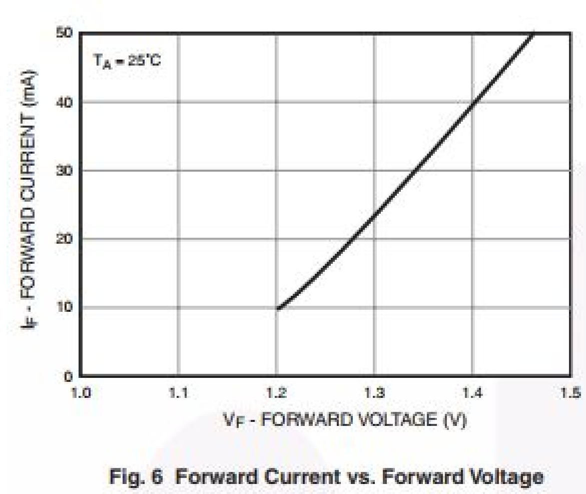


Figure 6 Forward Current vs. Forward Current

Based on I_F current assigned [5, 10, 15, 20] to the team find R1

Experiment 3 - Optimum R2 based on Team Assignment

1. **Grayscale target - White Paper**

2. Distance to target d - ***Based on team assignment***
3. LED current I_F - ***Based on team assignment***

Experimental Objective

One of the key objectives of this lab is to experimentally generate Figure 4 "Collector Current vs. Distance" between device and target and Figure 8 "Collector Current vs. Collector to Emitter Voltage" as shown in the QRE1113 Miniature Reflective Object Sensor datasheet.

The characteristic curve for the Phototransistor (Figure 8) will be generated from a gray scale as provided here. Base on experimental results you may be required to focus on additional gray scale images.

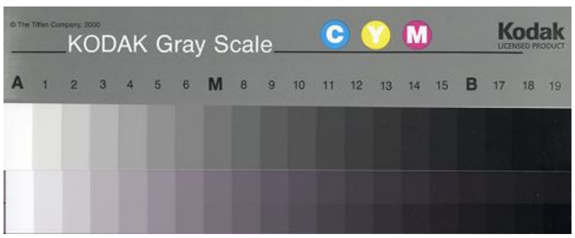


Figure 7 Sample Gray Scale Page

Experimentally, once an optimum distance has been experimentally determined, the transistor characteristic curve will be generated using a load line for each gray scale target (see Figure 9 "Sample transistor characteristic curve with load line").

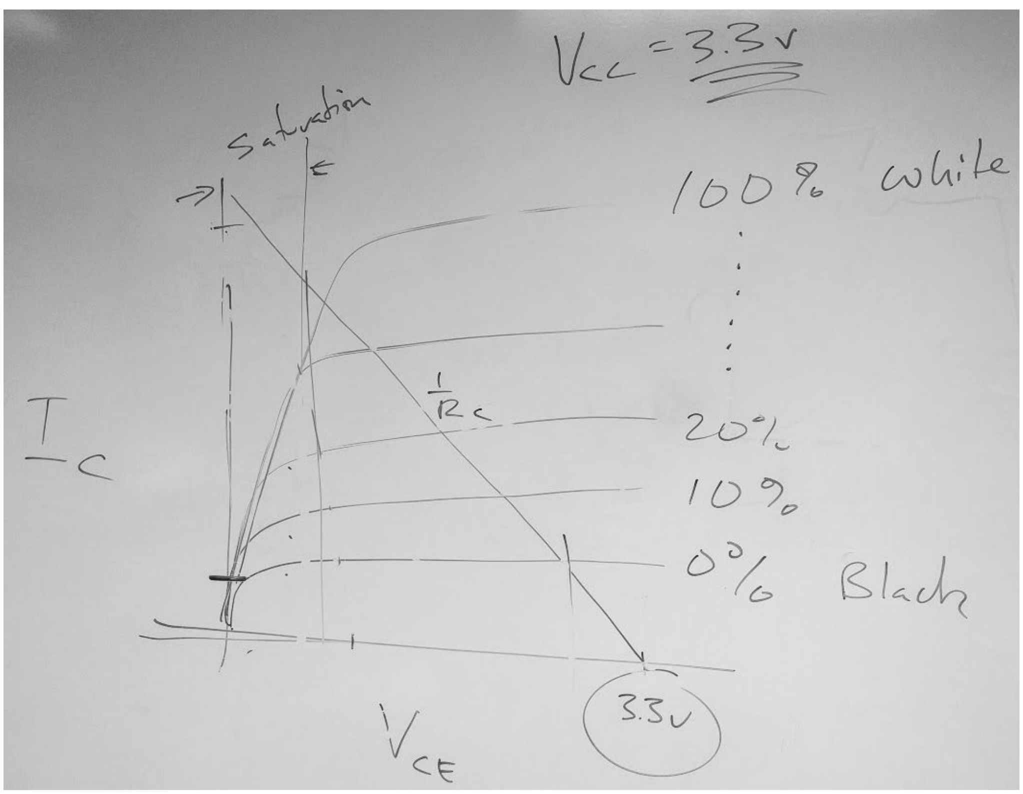


Figure 8 Collector Current vs. Collector to Emitter Voltage

Use the above information and your EE330 "Transistor Characteristic Curve Lab" to complete this lab. As before please collect data using a multimeter and your Arduino.

Based experimental results calculate R2

Reference Lab Experiments

- **Photo Transistor Characteristics by Dr. Gabriel M. Rebeiz**
- **Lesson 1452, Optoelectronics Experiment 6, Photodiode and Phototransistor Current Measurements**
- http://inst.eecs.berkeley.edu/~ee105/sp11/labs/Lab3.pdf
- http://archivio.iav.it/Doc/Vanni_Paolo/5CNT/EE332LE1rev3.pdf

Appendix

Appendix A - Survey of Reflective Sensors for Line Following Applications

By: Miki

Appendix B - How to measure Beta of a Phototransistor

By: Thomas

Appendix C - Capturing and Displaying data using Matlab

By: Thomas

Appendix D - Source Material

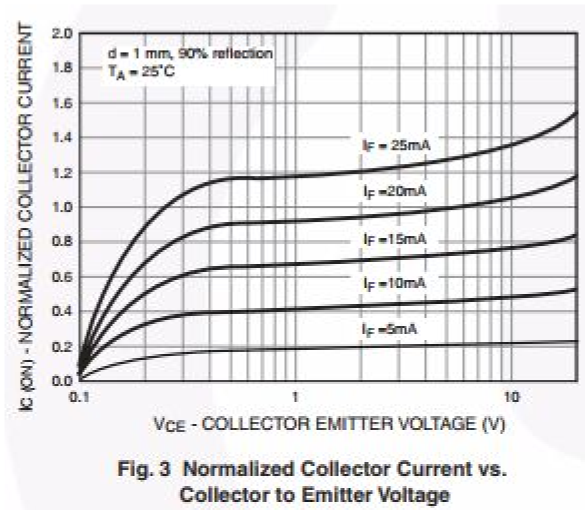


Figure 9 Normalized Collector Current vs. Collector to Emitter Voltage

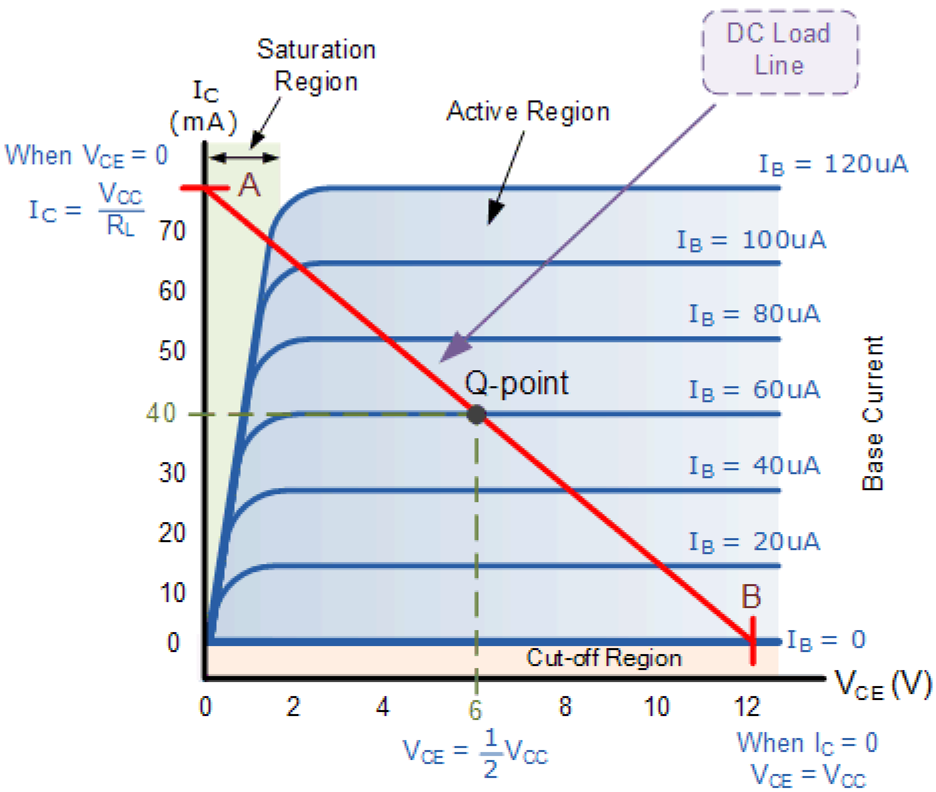


Figure 10 Sample transistor characteristic curve with load line